Macro-diversity Reception with Macro-diversity Selection and the Combination of Maximal Ratio Receivers

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ABSTRACT: *In the current work, we have used the macro-diversity reception with macro-diversity selectin and the combination of maximal ratio receivers. The propagation of signals at the multiple antennas at the receiver stage induces the non-line of-sight multipath fading channel and signals. The second level MRC also propagates inline shadowed multipath fading channel. With the help of Nakagami-m distribution we have defined the MRC receivers and the long term fading is explained using Gamma distribution. We have documented the impact of Rician fator and Nakagami-m severity parameter on LCR analysis using mean crossing rate and receiver output signal.*

Keywords: Macrodiversity, Microdiversity, Nakagami-m Fading, Rician Fading, Gamma, SC, MRC

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1. Introduction

Large scale fading and small-scale fading degrade outage probability, bit error probability and channel capacity of wireless communication system. MACD structures can be used in cellular mobile radio to reduce long-term fading effects and short term fading effects simultaneously [1]-[4]. In this paper MACD reception with SC receiver at macro level and MRC receiver at micro level are studied. MICD MRC receiver combines signal envelopes with two antennas at base station and MACD SC receiver combines signal envelopes average powers with two base stations. Signal at the first base station operating over Gamma shadowed non-line-of-sight short term fading channel and signals at the second MRC receiver operating over line-of-sight short term fading channel and signal envelopes variation at the first MRC receiver is described by using Nakagami-m distribution and signal envelopes variation at the second MRC receiver is modeled by using Rician distribution. The MACD SC receiver reduces Gamma long-term fading effects, the first MICD MRC receiver reduces Nakagami-m short term fading effects and the second MACD MRC reception reduces Rician short term fading effects on system performance. Outage probability and bit error probability are performance measures of the first order of wireless communication radio system and average level crossing rate and average fade duration are the second order performance measures of wireless communication system [5]-[8].

There are more works in open technical literature considering LCR of MACD receptions operating over shadowed multipath fading channels. In paper [9], average level crossing rate and average fade duration of MACD system with SC reception at macro level and MRC receptions micro level operating over Gamma shadowed correlated Nakagami-m short term fading are derived as expressions in closed form. The second order statistics of MACD structure consisting of SC MACD reception and MRC micro receptions in the presence of correlated Gamma long term fading and Rician short term fading are studied and evaluated in paper [10]. In the work [11], MACD reception in the presence of small scale κ-μ fading and Gamma large scale fading is considered and average level crossing rate and average fade duration are calculated. Outage probability and bit error probability of MACD system in the presence of Gamma shadowed, Rician fading channel are studied and derived.

In this paper, MACD structure with SC reception at macro level and MRC receiver at micro level where the first MRC receiver operates over non line-of-sight multipath fading channel and the second MRC receiver operating over line-of sight short term fading channel is considered. Signal at the first MRC receiver experiences Nakagami-m fading and signal at the second MRC receiver subjected to Rician short term fading. Signal envelope average power is described by using correlated Gamma distribution. In this paper, average level crossing rate of SC receiver output signal is calculated as expression in closed form. This expression can be used for calculation of average fade duration of proposed wireless MACD communications system [12]-[16].

2. Level Crossing Rate of Signal at Outputs of MRC Receivers

Signal envelopes at inputs in the first MRC receiver are denoted with x_1 and x_2 and at the inputs in the second MRC receiver with y_1 and y_2. Signal envelopes at outputs of MRC receiver are x and y and at the output of SC receiver signal envelope is denoted with z. Signal x_1 and x_2 follow Nakagami-m distribution:

$$p_{x_i}(x_i) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_1}\right)^m x_i^{2m-1} e^{-\frac{m}{\Omega_1}x_i^2}, \quad x_i \geq 0, \ i = 1,2. \tag{1}$$

where Gaussian noise is equally distributed between branch, squared random variable x can be written as sum of squared variables x_1 and x_2.

$$x^2 = x_1^2 + x_2^2. \tag{2}$$

The first derivative of x is:

$$\dot{x} = \frac{1}{x}\left(x_1\dot{x}_1 + x_2\dot{x}_2\right). \tag{3}$$

The first derivation of Nakagami-m random variable has zero mean Gaussian distribution with variance:

$$\sigma_{\dot{x}_2}^2 = \sigma_{\dot{x}_1}^2 = \pi^2 f_m^2 \frac{\Omega_1}{m}. \tag{4}$$

This $\dot{x}$ has Gaussian distribution with zero mean and variance:

$$\sigma_{\dot{x}}^2 = \frac{1}{x^2}\left(x_1^2\pi^2 f_m^2\frac{\Omega_1}{m} + x_2^2\pi^2 f_m^2\frac{\Omega_1}{m}\right) = \pi^2 f_m^2 \frac{\Omega_1}{m}. \tag{5}$$

The join probability density function of x and $\dot{x}$ is:

$$p_{x\dot{x}}(x\dot{x}) = p_x(x)\, p_{\dot{x}}(\dot{x}) = p_x(x)\frac{1}{\sqrt{2\pi}\sigma_{\dot{x}}} e^{-\frac{\dot{x}^2}{2\sigma_{\dot{x}}^2}} \tag{6}$$

The level crossing rate of the first MRC receiver output signal envelope is:

$$N_x = \int_0^\infty d\dot{x}\, \dot{x}\, p_{x\dot{x}}\left(x\dot{x}\right) = p_x\left(x\right)\frac{\sigma_{\dot{x}}}{\sqrt{2\pi}}. \tag{7}$$

Random variable x fallow χ^2 distribution:

$$p_x\left(x\right) = \frac{2}{\Gamma\left(2m\right)}\left(\frac{m}{\Omega_1}\right)^{2m} x^{4m-1} e^{-\frac{m}{\Omega_1}x^2},\ x \geq 0. \tag{8}$$

After substituting the expressions for N_x becomes:

$$N_x = \frac{2\pi f_m}{\Gamma\left(2m\right)\sqrt{2\pi}}\left(\frac{m}{\Omega_1}\right)^{2m-1/2} x^{4m-1} e^{-\frac{m}{\Omega_1}x^2},\ x \geq 0 \tag{9}$$

Squared signal y is:

$$y^2 = y_1^2 + y_2^2. \tag{10}$$

The first derivative of y is:

$$\dot{y} = \frac{1}{y}\left(y_1\dot{y}_1 + y_2\dot{y}_2\right) \tag{11}$$

The first derivation of Rician random variable has zero mean Gaussian distribution with variance:

$$\sigma_{\dot{y}_1}^2 = \sigma_{\dot{y}_2}^2 = \pi^2 f_m^2 \frac{\Omega_2}{\kappa+1}. \tag{12}$$

This random variable $\dot{y}$ has zero mean Gaussian variance with variance:

$$\sigma_{\dot{y}}^2 = \pi^2 f_m^2 \frac{\Omega_2}{\kappa+1}. \tag{13}$$

The level crossing rate of the second MRC receiver output signal envelope is:

$$N_y = p_y\left(y\right)\frac{\sigma_{\dot{y}}}{\sqrt{2\pi}} \tag{14}$$

Random variable y follows χ^2 distribution:

$$p_y\left(y\right) = \frac{4\left(\kappa+1\right)y}{2e^{2\kappa}\Omega_2} e^{\frac{2\left(\kappa+1\right)}{\Omega_2}y^2} I_1\left(4\sqrt{\frac{\kappa\left(\kappa+1\right)}{2\Omega_2}}\right) = \frac{2\left(\kappa+1\right)y}{e^{2\kappa}\Omega_2}$$

$$\times e^{\frac{2\left(\kappa+1\right)}{\Omega_2}y^2} \sum_{i_1=0}^{\infty}\left(2\sqrt{\frac{\kappa\left(\kappa+1\right)}{2\Omega_2}}\right)^{2i_1+1} \frac{1}{i_1!\Gamma\left(i_1+2\right)} y^{2i_1+2}. \tag{15}$$

After substituting the expressions for average level crossing rate becomes:

$$N_x = \frac{4(\kappa+1)^{1/2}\pi f_m}{e^{2\kappa}\Omega_2^{1/2}\sqrt{2\pi}\,2^{1/2}} e^{\frac{2(\kappa+1)}{\Omega_2}y^2} \times \sum_{i_1=0}^{\infty}\left(2\sqrt{\frac{\kappa(\kappa+1)}{2\Omega_2}}\right)^{2i_1+1} \frac{1}{i_1!\Gamma(i_1+2)} y^{2i_1+2} \tag{16}$$

Signal envelope powers Ω_1 and Ω_2 follow correlated Gamma distribution [17]:

$$p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) = \frac{1}{\Gamma(c)(1-\rho^2)\rho^{c-1}\Omega_0^{c+1}} I_{c-1}\left(\frac{2\rho}{\Omega_0(1-\rho^2)}\Omega_1^{1/2}\Omega_2^{1/2}\right) \times e^{-\frac{\Omega_1+\Omega_2}{\Omega_0}} = \frac{1}{\Gamma(c)(1-\rho^2)\rho^{c-1}\Omega_0^{c+1}} \sum_{i_1=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_1+c-1} \times \frac{1}{i_1!\Gamma(i_1+c)!}\Omega_1^{i_1+c-1}\Omega_2^{i_1+c-1} e^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho^2)}}. \tag{17}$$

where c is Gamma shadowing severity parameter, ρ is Gamma correlation coefficient and Ω_0 is average power of Ω_1 and Ω_2.

When c goes to infinity shadowed multipath fading channel becomes multipath fading channel. When ρ goes to one, the least signal occurs simultaneously at bout MRC receivers. Diversity gain decreases as correlation coefficient increases.

3. Level Crossing Rate of SC Receiver Output Signal Envelope

Macrodiversity SC receiver selects microdiversity MRC receivers with the highest signal envelope average power at inputs to provide service to mobile user. This, level crossing rate of SC receiver output signal is:

$$N_z = \int_0^{\infty} d\Omega_1 \int_0^{\Omega_1} d\Omega_2\, N_{x/\Omega_1}\, p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) + \int_0^{\infty} d\Omega_2 \int_0^{\Omega_2} d\Omega_1\, N_{y/\Omega_2}\, p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) = J_1 + J_2 \tag{18}$$

The integral J_1 is [17]:

$$J_1 = \frac{2\pi f_m}{\sqrt{2\pi}\,\Gamma(2m)} m^{2m-1/2} x^{4m-1} \frac{1}{\Gamma(c)(1-\rho^2)\rho^{c-1}\Omega_0^{c+1}} \times \sum_{i_1=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_1+c-1} \frac{1}{i_1!\Gamma(i_1+c)}\frac{1}{i_1+c} \times \sum_{j_1=0}^{\infty}\frac{1}{(i_1+c+1)_{(j_1)}}\left(mx^2\Omega_0(1-\rho^2)\right)^{i_1+c-m+1/4+j_1/2} \tag{19}$$

$$\times\left(\frac{1}{\Omega_0(1-\rho^2)}\right)^{j_1} K_{2i_1+2c-2m+1/2+j_1}\left(2\sqrt{\frac{mx^2}{\Omega_0(1-\rho^2)}}\right).$$

The integral J_2 is [17]:

$$J_2 = \frac{4(\kappa+1)^{1/2}\pi f_m}{e^{2\kappa}\sqrt{2\pi}\,2^{3/2}}\sum_{i_1=0}^{\infty}\left(2\sqrt{\frac{\kappa(\kappa+1)}{2\Omega_2}}\right)^{2i_1+1}\frac{1}{i_1!\Gamma(i_1+2)}z^{2i_1+1}$$
$$\times\frac{1}{\Gamma(c)(1-\rho^2)\rho^{c-1}\Omega_0^{c+1}}\sum_{i_2=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_2+c-1}\frac{1}{i_2!\Gamma(i_2+c)}$$
$$\times\frac{1}{i_2+c}\sum_{j_1=0}^{\infty}\frac{1}{(i_2+c+1)_{(j_1)}}\left(mz^2\frac{\Omega_0(1-\rho^2)}{2}\right)^{i_2+c-1+j_1/2-i_1/2} \tag{20}$$
$$\times\left(\frac{1}{\Omega_0(1-\rho^2)}\right)^{j_1}K_{2i_2+2c-2+j_1-i_1}\left(2\sqrt{\frac{2mz^2}{\Omega_0(1-\rho^2)}}\right).$$

4. Numerical Results

Level crossing rate of resulting process at output of macrodiversity SC receiver versus of SC receiver output signal for several values Nakagami-m short term fading severity parameter, Rician *k* factor and Gamma long term fading severity parameter is shown at Figure 1.

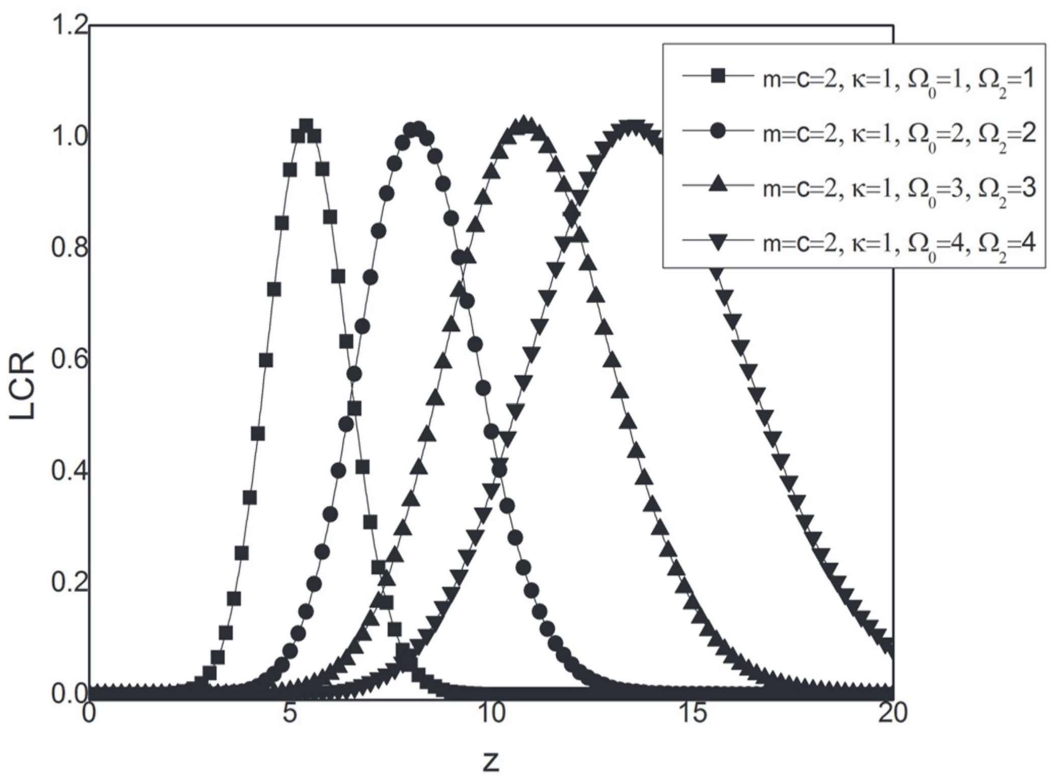

Figure 1. Level crossing rate (LCR) depending on the envelope *z*, when $m = c = 2$, $\kappa=1$ and different values of Ω_0 and Ω_2

Level crossing rate getting wider for higher values of Ω_0 and Ω_2. Resulting signal has higher influence on level crossing rate for lower values of resulting signal. Level crossing rate decreases as Nakagami-m severity parameter has higher influence on level crossing rate for lower values resulting signal and higher values of Nakagami-m short term fading severity parameter. Level crossing rate increases when Gamma long term fading severity parameter decreases. The influence of Gamma long term fading severity parameter on level crossing rate is higher for lower values of resulting signal for lower values of resulting signal for lower values of Nakagami-m short term fading severity parameter and for higher values of Gamma long term fading severity parameter..

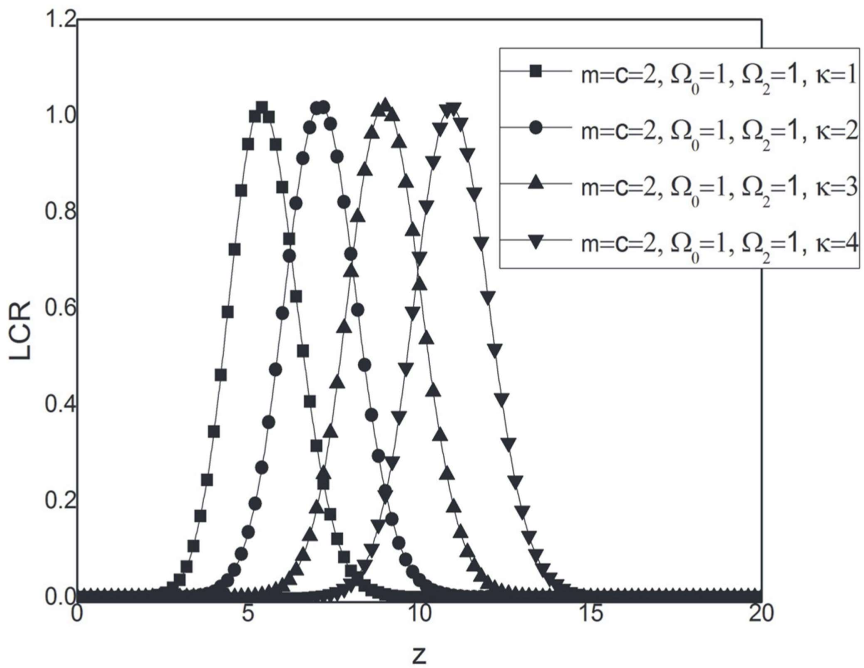

Figure 2. Level crossing rate (LCR) depending on the envelope z, when $m = c = 2$, $\Omega_0 = 1$ and different values of κ

Level crossing rate decreases when Rician *k* factor increases in Figure 2. Rician *k* factor has higher influence on level crossing rate for lower values of Rician *k* factor. Also, Rician *k* factor has higher influence on level crossing rate for lower values of *Nakagami-m* short-term fading severity parameter and lower values of Gamma long term fading severity parameter.

5. Conclusion

Macrodiversity system with selection combining receiver at macro level and two maximal ratio combining receiver at micro level signal, at the first MRC receiver operate over non line-of-sight short term fading and signal at the second MRC receiver operate over line-of-sight multipath fading channel is analysed. Nakagami-m distribution is used to describe signal envelope at the first MRC receiver and Rician distribution is used to described signal envelope at the second MRC receiver. Long term fading is described by using correlated Gamma distribution. Macro SC receiver reduces Gamma long term fading effects on system performance the first MRC receiver reduces Nakgami-m short term fading effects on system performance and the second MRC receiver reduces Rician short term fading effects on system performance. In this paper, level crossing rate of SC receiver output signal is calculated as expression closed form. By using this expression, average fade duration of macrodiversity wireless communication system can be calculated. Also, by using derived expression, level crossing rate of macrodiversity system operating over Gamma shadowed, Rayleigh multipath fading channel can be evaluated. The influence of Nakagamim shape parameter, Rician κ factor and Gamma long term severity parameter on level crossing rate is studied and discussed. Level crossing rate decreases as Nakagami-m shaping parameter increases. When Rician factor or dominant component power increases level crossing rate has lower values. Level crossing rate decreases when Gamma parameter increases and when Gamma parameter goes to infinity, Gamma shadowed multipath fading channel becomes multipath fading channel. When correlation coefficient goes to one macro diversity system becomes micro diversity system.

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